CPMA

Centrifugal Particle Mass Analyzer

Application Note: CPMA04v02

Use of the Cambustion CPMA for absolute mass calibration of the Single Particle Soot Photomoter (SP2)

Cambustion

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Introduction

The Cambustion Centrifugal Particle Mass Analyzer (CPMA) is an aerosol classifier, which allows direct selection of charge-neutralised aerosol particles *according to their mass-to-charge ratio*. The CPMA may be considered an equivalent instrument for particle mass selection to the Differential Mobility Analyzer (DMA), which allows selection of charge-neutralised particles according to their electrical mobility (drag-to-charge ratio). The CPMA is used with an external charge-neutraliser, which may be of the radioactive, X-ray or corona types. The CPMA uses a balance between electrostatic and centrifugal forces to select particles of a given mass-to-charge ratio. Novel features ensure a higher throughput of particles of the selected mass-to-charge ratio, compared with earlier instruments such as the Aerosol Particle Mass analyzer (APM; Ehara et al., 1996)

The CPMA principle is described in further detail here: http://www.cambustion.com/products/cpma/

Use for absolute mass calibration of SP2

The single particle soot photometer (SP2; Stephens et al. 2003) uses laser-induced incandescence to heat refractory black carbon (BC) particles to ~4000K, and measures the intensity of the emitted radiation. The peak of the LII intensity is proportional to the BC mass contained within the particle (shown in Figure 2, right)

The SP2 is commonly calibrated using BC proxies such as Fullerene Soot (FS; Irwin et al. 2013, and references therein), though many calibrations are performed with assumptions from the very beginning, e.g. by assuming the density of FS typically to be that of graphene (i.e. 1.8 g/cm^3). Such assumptions are required if one is calibrating the SP2 using a DMA—as the DMA classifies by electrical mobility, not particle mass. However, a much more accurate method is to directly calibrate the SP2 using a <u>mass</u> classifier, such as the CPMA.
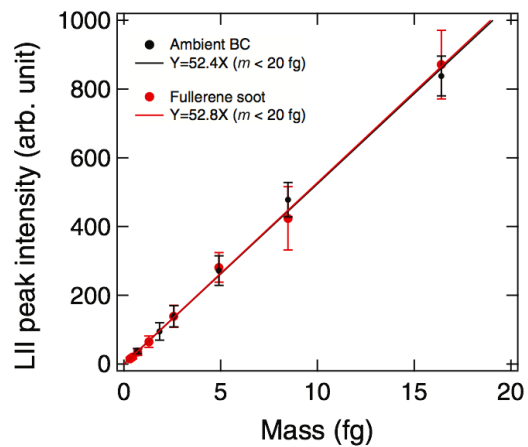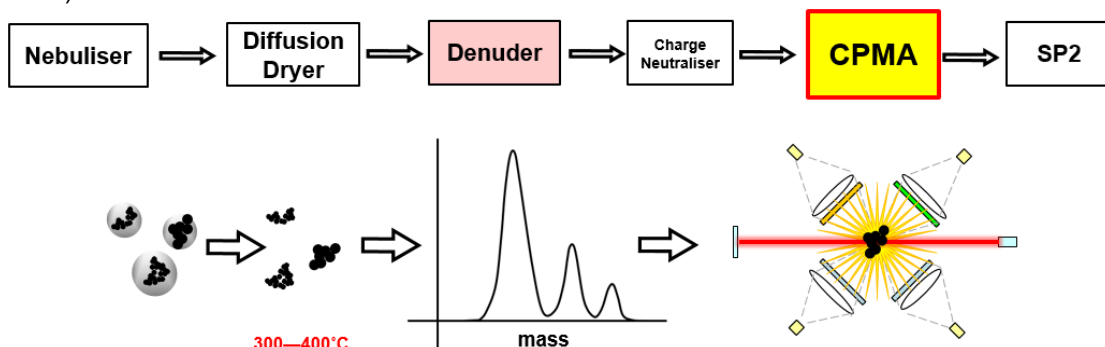

Figure 2: Mass calibration of the SP2 is performed by relating LII peak intensity to particle mass

In addition, the use of a thermal denuder at around 350°C for BC mass calibration is advised, even when using "pure" FS, as non-BC material is present in the aerosol phase (Irwin et al. 2013).

A recommended experimental setup for the mass calibration of the SP2 is shown in Figure 3. Nebulised fullerene soot is dried, and then heated to ~350°C to partition non-BC material to the gaseous phase. The charge-neutralised aerosol is then classified by the CPMA to a predetermined mass setpoint. A mass resolution (R_m) value of 3 is recommended where possible to ensure a tight transfer function—this is approximately equivalent to a DMA resolution, R_s, of 10. The particles are then detected by the SP2, and the incandescence values recorded. The peak of the incandescence signal is then plotted against CPMA setpoint mass, which should reveal a straight-line plot below ~20 fg. Alternatively, the same calibration can be performed using ambient aerosol, if concentrations are high enough.

But what about multiple charging…?

As the CPMA classifies particles by their mass-to-charge ratio, particles of twice the mass of the target setpoint will pass through the classifier if they are doubly charged. The same for particles of three times the mass, and triply charged (and so on). The result is raw data that looks like that shown in Figure 4, where the CPMA mass setpoint was stepped downwards. For any given time at a particular setpoint, the multiple charged particles clearly form in their own modes (Figures 4 & 5). These are easily identified from the high-gain broadband and narrowband detectors of the SP2. Also note the presence of uncharged particles of low mass (though the use of a corona charger will reduce the number of these particles to almost zero).
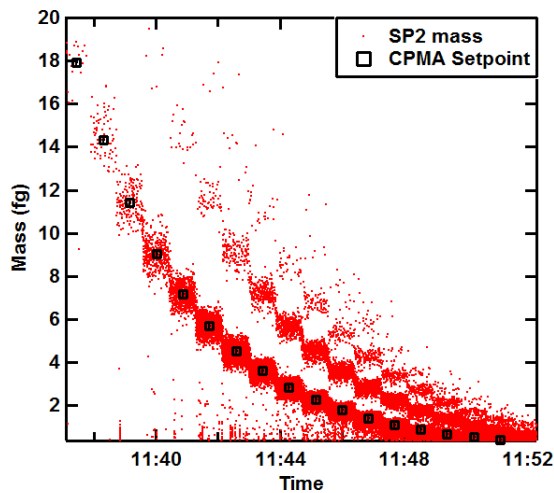
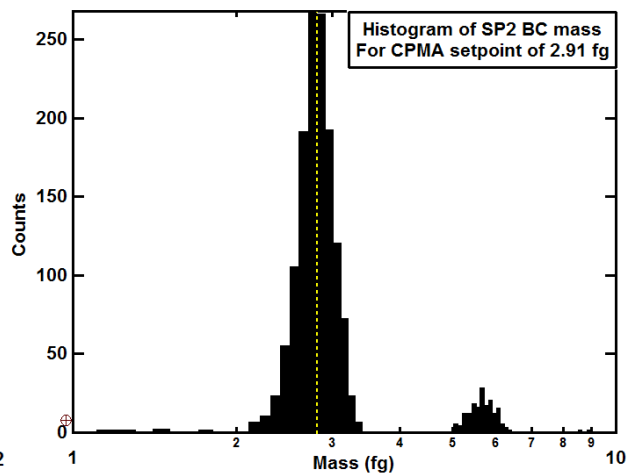Figure 4: Time series of CPMA setpoints and corresponding SP2 masses for each setpoint

Figure 5: Histogram of SP2 counts for CPMA setpoint of 2.91 fg

As implied by the instrument's name, the single particle soot photometer will identify particles on a per-particle mass basis, and so the calibration outlined above is relatively simple and straightforward. If lower concentrations are acceptable (i.e. for atomised BC rather than ambient), then a DMA and CPMA can be used in tandem, to produce a single mode of known particle mass. Here, the DMA is used to arbitrarily pick the peak of the CPMA's output, and pass it through with a wide transfer function (i.e. the DMA must be set with a low sheath-to-
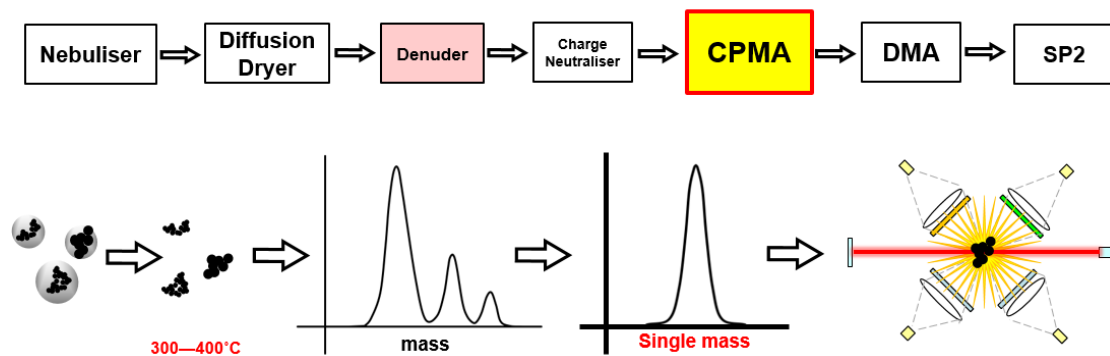
Figure 6: An alternative experimental setup for SP2 mass calibration

aerosol flow ratio to ensure that the desired CPMA mass is not sub-sampled). An example of this setup is shown in Figure 6.

After taking the data, the simplest way to process the calibration is to use the analysis software package Igor Pro, and the PSI SP2 toolkit (video). There are numerous in-depth videos on Youtube showing how to use the toolkit, so we will not go into that detail here.

Figure 7 (right) shows a screenshot from the PSI SP2 toolkit, where calibration is performed for a setup as shown in Figure 3 (i.e. just a single classifier). The set-point mass corresponds to the main (largest) peak of the logarithm of the low gain broadband (LII) peak intensity (analogous to the raw data shown in Figure 5).
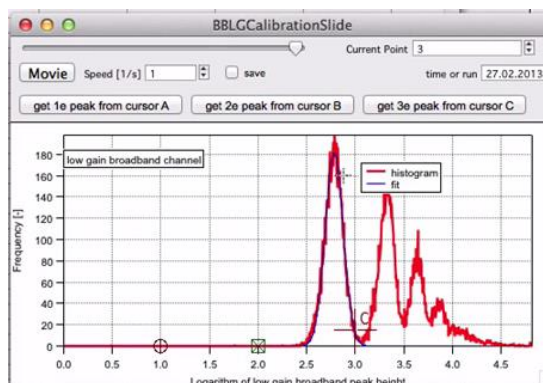

Figure 7: PSI SP2 toolkit in Igor Pro

Similar techniques can be employed for calibrating conventional LII techniques (total mass, with pulsed lasers), such as the experiments performed by Bambha et al. (2013).

Summary

The CPMA is a powerful tool for the calibration of multiple aerosol instruments, and is especially powerful for instruments detecting black carbon laser-induced incandescence. The high transmission efficiency, low uncertainty, and absolute mass classification make the CPMA the ideal instrument for calibrating the SP2.

Further Reading

CPMA: www.cambustion.com/products/cpma
UDAC: www.cambustion.com/products/udac
Publications   http://www.cambustion.com/publications/pubinst/CPMA
SP2:   http://dropletmeasurement.com/single-particle-soot-photometer-sp2

Publications referred to in the text

Bambha, R. P., Dansson, M. A., Schrader, P. E., Michelsen, H. A. "Effects of volatile coatings on the laser-induced incandescence of soot"; *Applied Physics B; Lasers and Optics* (2013) 112:343–358
DOI 10.1007/s00340-013-5463-9

Ehara, K., Hagwood C., Coakley, K. J., "Novel method to classify aerosol particles according to their mass-to-charge ratio — Aerosol Particle Mass Analyser"; *Journal of Aerosol Science.* Volume 27, Issue 2, Pages 217–234 (1996)
DOI: 10.1016/0021-8502(95)00562-5

Irwin, M., Kondo, Y., Moteki, N. and Miyakawa, T. (2013). "Evaluation of a Heated-Inlet for Calibration of the SP2". *Aerosol Science and Technology,* 47(8), 895-905
DOI: 10.1080/02786826.2013.800187

Stephens, M., Turner, N., and Sandberg, J. (2003). Particle Identification by Laser-Induced Incandescence in a Solid-State Laser Cavity. Applied Optics, 42:3726–3736
DOI: 10.1364/AO.42.003726